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CEL 10K PROPELLANT-ACTUATED ANCHOR

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CEL 10K PROPELLANT-ACTUATED ANCHOR

By

J. F. Wadsworth and R. J. Taylor

June 1976

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CEL has developed a new lightweight propellant-actuated embedment anchor with a nominal long-term holding capacity of 10,000 pounds (45 kN). Through the use of stock components, the anchor can be inexpensively fabricated and used. Land tests have demonstrated the structural integrity of the design and verified the predicted ballistic performance. Sea tests were conducted in a coral seafloor at Midway Island. The anchors that were successfully embedded indicated holding capacities on the order of 30,000

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1. Propellant-Actuated Anchor 2. Land Tests 3. Sea Tests I. 3.1330-1

CEL has developed a new lightweight propellant-actuated embedment anchor with a nominal long-term holding capacity of 10,000 pounds (45 kN). Through the use of stock components, the anchor can be inexpensively fabricated and used. Land tests have demonstrated the structural integrity of the design and verified the predicted ballistic performance. Sea tests were conducted in a coral seafloor at Midway Island. The anchors that were successfully embedded indicated holding capacities on the order of 30,000 pounds (45 kN). Further testing is required to ascertain the system's reliability in other seafloor materials, but the 10K anchor should provide the Navy with an easily handled, medium-holding-capacity anchor.

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INTRODUCTION

A new propellant-actuated anchor (CEL 10K) has been designed and fabricated for the Chesapeake Division of NAVFAC (Figure 1). The experience gained during the development of the CEL 20K anchor* allowed a straightforward 10K anchor design effort. During the testing phase for the CEL 20K anchor, many improvements were envisioned that would simplify operational and handling characteristics and reduce cost; these improvements were incorporated in the CEL 10K anchor design. The anchor is designed to operate at depths of 25 to 20,000 feet (7 to 6,100 m) and will develop at least 10,000 pounds (45 kN) of long-term holding capacity in seafloor soils, rock, and coral. Holding capacity will vary between 10 and 50,000 pounds (45 to 225 kN) depending upon seafloor type.

Because the anchor was designed for lower holding capacity applications, it should be useful for mooring buoys, small vessels, instrument arrays, causeways, and a variety of other surface and subsurface structures. If the anchor is to be used for these applications, it must exhibit advantages over the conventional approaches to anchoring.

In addition to the characteristic advantages of the direct embedment anchor – such as the ability to resist multidirectional loadings, high anchoring efficiency, reduction in required line scope, and operability in competent seafloors – the CEL 10K anchor was designed to be low in cost and light weight. Total anchor system weight is about 700 pounds, (320 kg) and the system is fabricated for less than $2,500. In shallow water, the cost of expendable components is about $450.

This report describes the anchor and details the land testing program used to verify gun performance and its first in-water firings.

DESCRIPTION OF EQUIPMENT

The anchor consists of two major parts (Figure 2) – the gun assembly and the fluke assembly. Table 1 describes the anchor with a sand fluke and a clay fluke attached. The new anchor weighs about 625 to 700 pounds (285 to 320 kg) and measures about 6 feet (1.8 m) in overall length with the touchdown probe extended. The design uses stock components and minimizes machined parts, thereby allowing faster and simpler fabrication.

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* R. J. Taylor (1976). Technical Report R-837: CEL 20K Propellant-actuated anchor. Civil Engineering Laboratory, Port Hueneme, CA.

Table 1. Characteristics of CEL 10K Propellant-Actuated Anchor

Description	Anchor With—	
	Sand Fluke	Clay Fluke
Length, ft (m)	6 (1.83)	6 (1.83)
Diameter, ft (m)	2 (0.61	2 (0.61)
Nominal weight, lb (kg)	700 (3	700 (317.1)
Gun assembly	480 (	480 (217.4)
Fluke assembly	148	173 (78.4)
Total	628 (384.5)	653 (295.8)
Operating depth, ft (m)	25-20,000 (6.6-6,100)	25-20,000 (6.6-6,100)
Rated holding capacity, lb (kN)	10,000 (44.5)	10,000 (44.5)

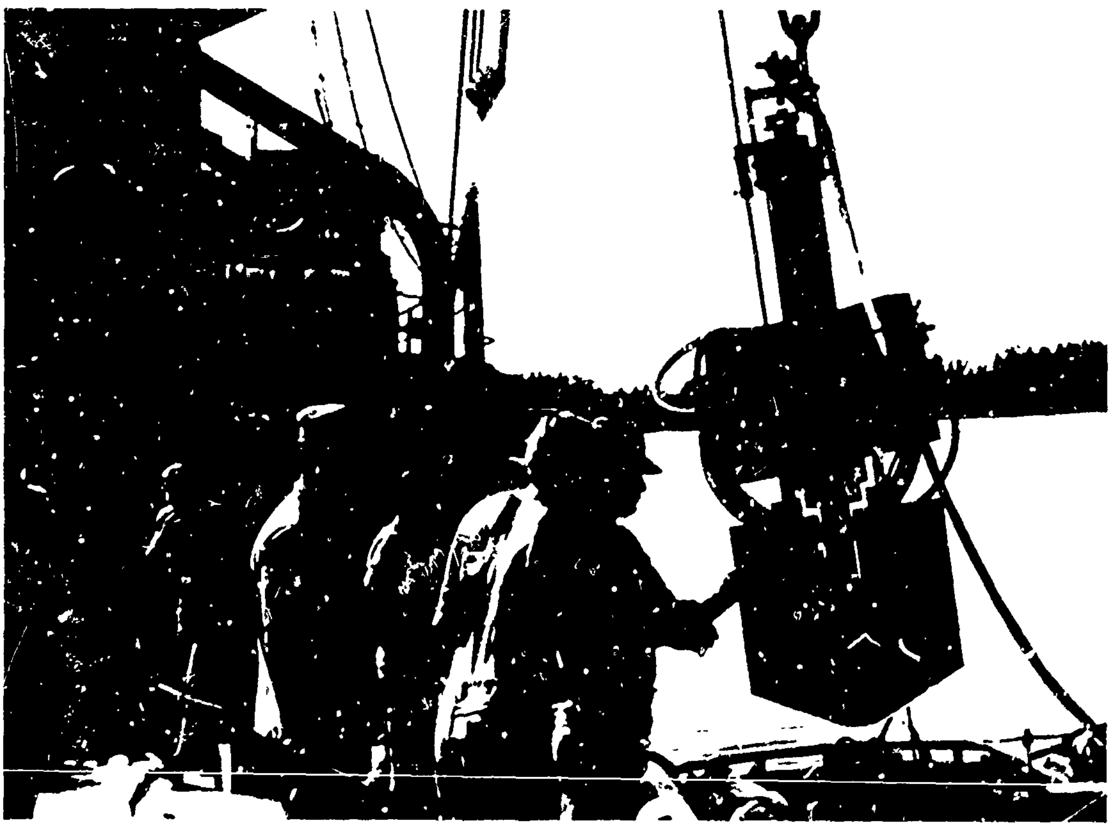

Figure 1. CEL 10K Propellant-actuated anchor.

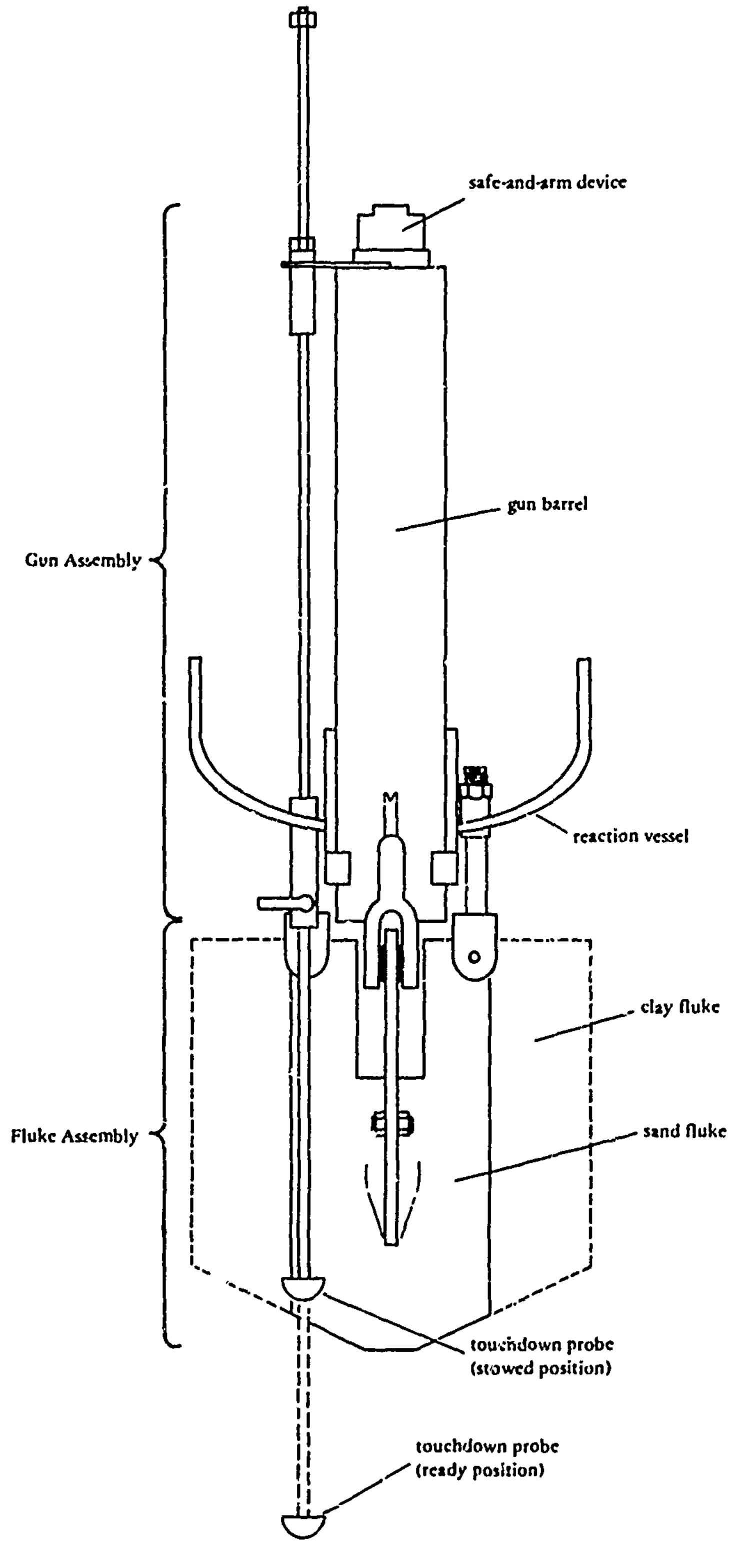

Figure 2. Schematic of the CEL 10K propellant-actuated anchor.

Functional Description

The firing mechanism is mechanical; spring energy is used to drive a firing pin into the primer. After lifting the anchor off the deck, only the touchdown probe is lowered to prepare the anchor for installation. The anchor is still ''safe'' until it reaches a depth of 10 to 12 feet (3 to 4 m). At that depth, a hydrostatic lock is released, allowing the trigger of the safe-and-arm device (S/A) free travel.

Embedment of the anchor projectile occurs when the touchdown probe touches the seafloor. The probe slides, triggering the S/A, which in turn detonates the propellant charge. The pins restraining the fluke assembly shear when the barrel pressure reaches 5,000 psi (34.5 MPa) over ambient water pressure, and the anchor projectile is propelled downward into the seafloor with the downhaul cable. The fluke keys into its maximum resistance position with an upward pull. The gun assembly is expendable in deep water at present, but deep-water retrieval methods described by Taylor* are pertinent.

Anchor Design

Fluke assembly. Three types of flukes can be used with the CEL 10K anchor: a sand fluke (1 x 2-foot, 31 x 61-cm), a clay fluke (2 x 2-foot, 61 x 61-cm), and a rock fluke (to be designed). The clay fluke is square-shaped because recent tests have indicated that a square fluke is best for use in soft clay seafloors. In addition, the 10K anchor utilizes a mechanical S/A, and it is advantageous to keep the touchdown rod as short as possible to minimize potential binding. Handling and fabrication are also further simplified by using the same length of fluke and touchdown rod for both sand and clay anchors. Since predicted anchor performance gave more than enough penetration to achieve the desired holding capacities, it was possible to sacrifice some penetration in order to keep both flukes the same length. The fluke characteristics are outlined in Table 2. The main plate for the flukes is flat. To balance the 10K projectile the flat plate is mounted below the piston axis enough to counteract the weight of the keying arm plate.

The 10K fluke assemblies also have a modified connection between the downhaul cable and fluke. The connection is a single link that leads to the downhaul cable socket (Figure 3). Both the socket and line are pinned together through a plate welded to the piston.

Gun assembly. The gun assembly of the anchor is comprised of the gun tube, the reaction vessel, the firing system, and the cartridge assembly (Figure 2). The gun barrel of the 10K anchor is a smooth-bore steel tube designed to operate at 50,000 psi (345 MPa). The breech block is threaded into the end of the gun tube, and then the S/A (purchased from the Magnavox Co.) is in turn threaded into the breech block. The reaction vessel is a reinforced pipe cap 2 feet (0.6 m) in diameter mounted at the muzzle end of the gun tube to entrap water and reduce

* Taylor (1976), Ibid.

recoil of the gun assembly; analysis indicates the recoil will be a maximum of 15 feet (4.6 m). The firing assembly is a mechanical system that triggers the embedment sequence (Figure 4). A solid steel rod, which can be stowed with the probe above the end of the fluke, serves as the touchdown probe. When the rod is pulled down, spring-loaded pins lock the rod to the firing ring. Upon probe contact with the seafloor, the firing ring is moved upward, engaging the trigger arm of the S/A and releasing the firing pin. The S/A has a hydrostatic lock that prevents firing above a water depth of 10 to 12 feet (3 to 4 m). The cartridge assembly consists of an aluminum or steel cartridge base that is epoxied to a phenolic cartridge case to form the propellant container. The ordnance consists of 5-inch (127 mm)/38 caliber gun propellant (M6) and a shortened M58 primer (Figure 5).

Table 2. Characteristics of CEL 10K Anchor Flukes

Description	Sand	Clay
Length, in. (cm)	24 (61)	24 (61)
Width, in. (cm)	12 (30.5)	24 (61)
Thickness, in. (mm)	1/2 (13)	1/2 (13)
Plan area, ft^2 (m^2)	1.94 (0.148)	3.66 (0.297)
Material	A514 or A517	A514 or A517
Piston weight, lb (kg)	69 (31.3)	69 (31.3)

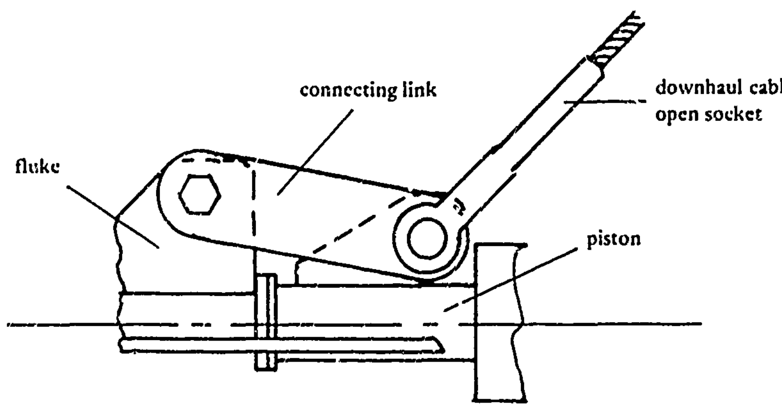

Figure 3. CEL 10K anchor fluke-to-downhaul-cable connection.

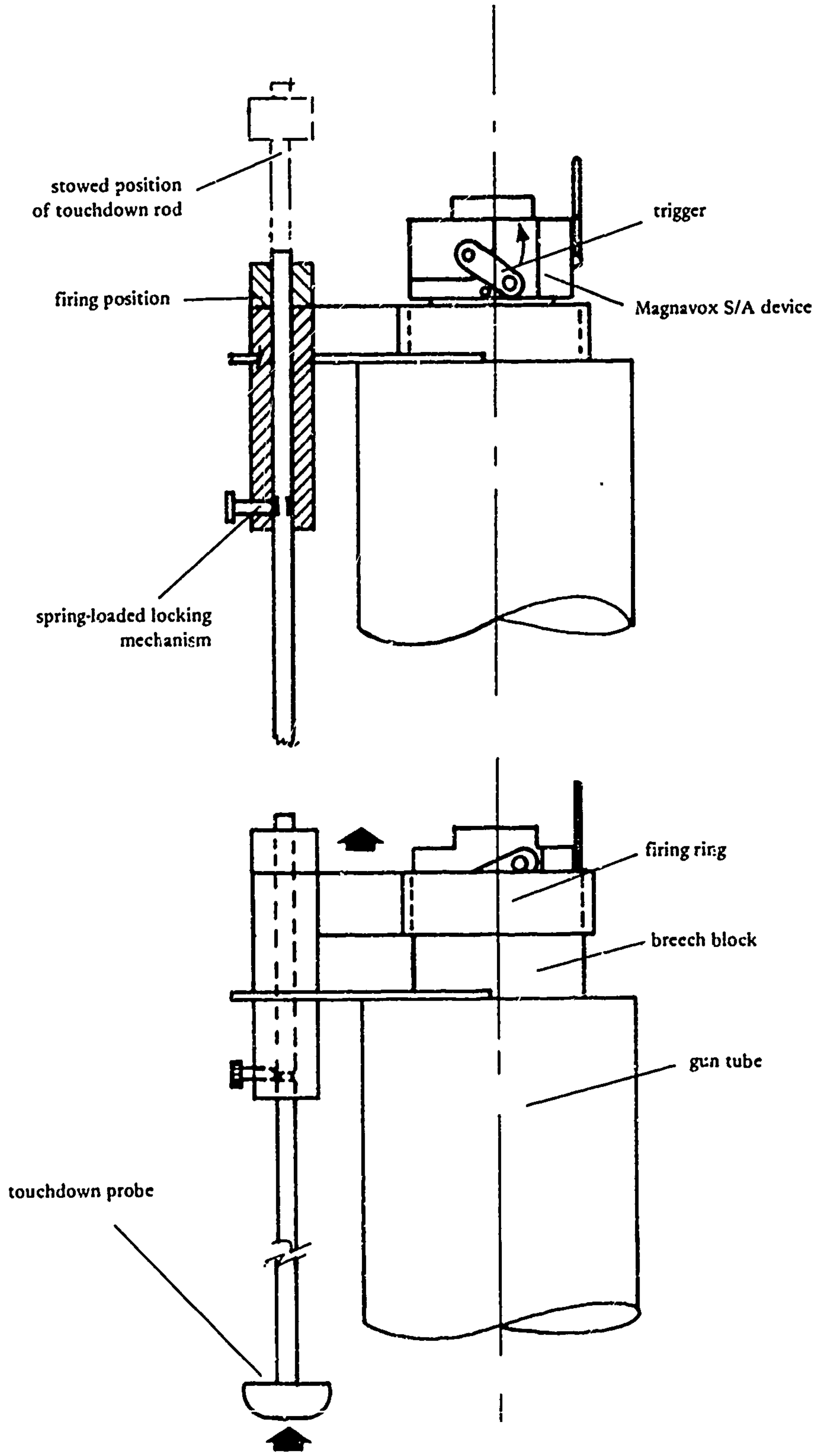

Figure 4. CEL 10K anchor firing mechanism.

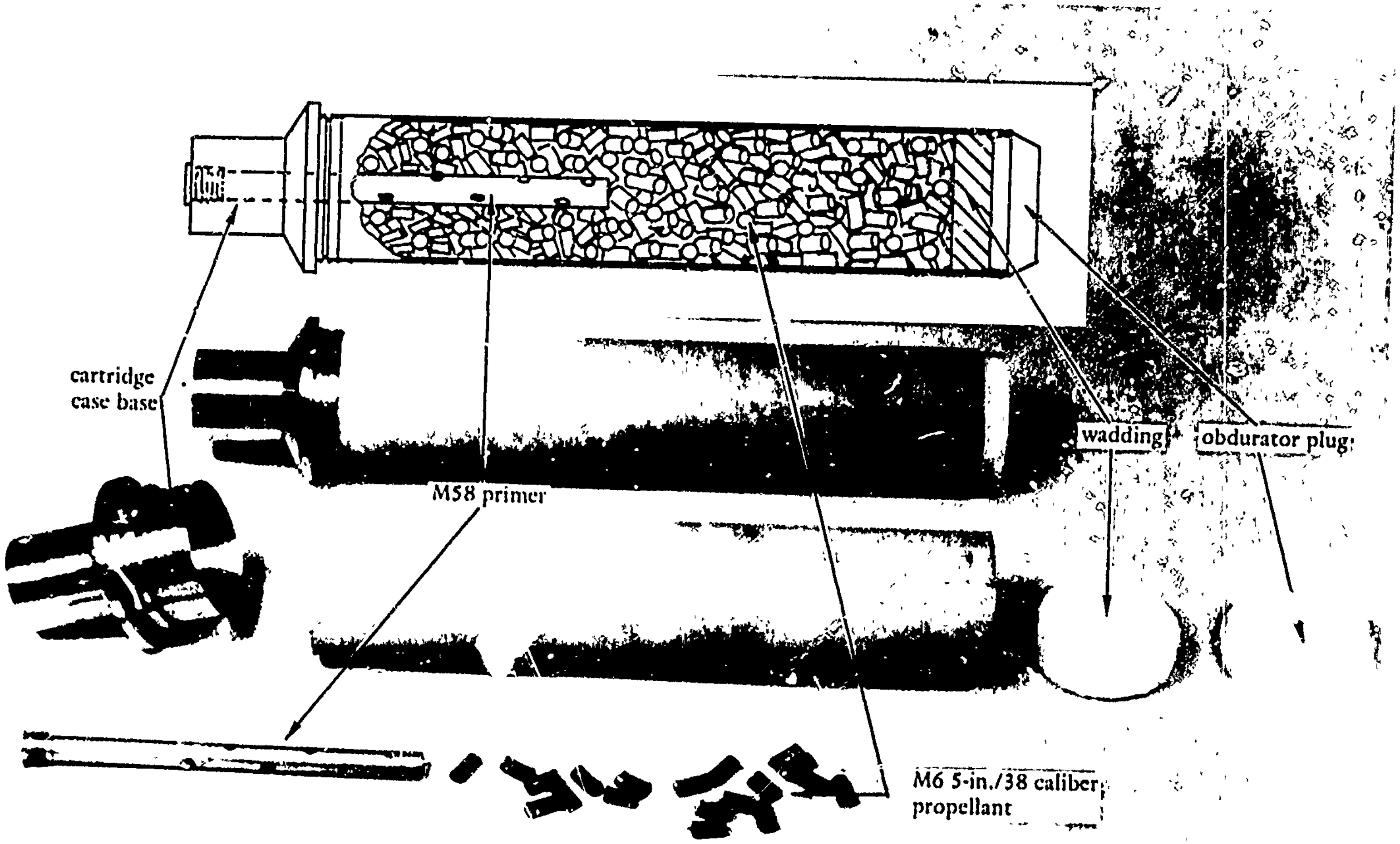

Figure 5. CEL 10K anchor cartridge assembly.

PROJECTED BALLISTIC PERFORMANCE

The Naval Ordnance Station, Indian Head, Maryland, selected smokeless propellant (M6) with 0.0579-inch (1.37 mm) web thickness (material thickness between perforations) as the most suitable propellant for the 10K anchor.* This was based on desired performance criteria of: (1) maximum operating pressure of 50,000 psi (345 MPa), (2) maximum acceleration of 2,000 g's, and (3) minimum projectile velocity of 250 fps (76 mps).

A computer program for simulation of propellant-actuated anchor performance was used to predict the 10K anchor ballistics at a range of depths and charge weights. The results of the simulation are presented graphically in Figures 6, 7, and 8. Using the plots (Figures 6 and 7) of projectile velocity versus water depth for each projectile, charge weight for peak performance (Figure 8) was determined with the limiting condition of 2,000 g's acceleration for the 1 x 2-foot (31 x 61-cm) fluke and 50,000 psi (345 MPa) for the 2 x 2-foot (61 x 61-cm) fluke. These charge weights are practically similar for both flukes. It appears that a fluke larger than the 2 x 2-foot (61 x 61-cm) fluke could be effectively used with this gun system to improve anticipated performance in clay seafloors. Once the system is used more, this decision can be made more reliably.

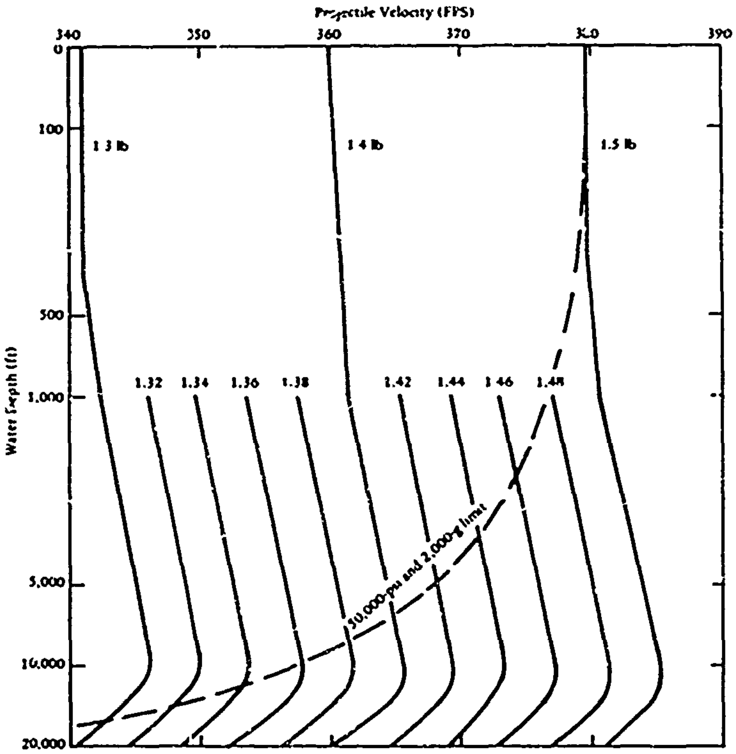

Figure 6. Projectile velocity versus water depth for the CEL 10K anchor at various charge weights. The projectile used is the 173-pound, 2 x 2-foot fluke; the propellant is M6, 0.0579-inch web.

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* J. M. Holden (1975). Technical Report IHTR 438: Propulsion system development for a 10,000-pound capacity embedment anchor. Naval Ordnance Station, Indian Head, MD.

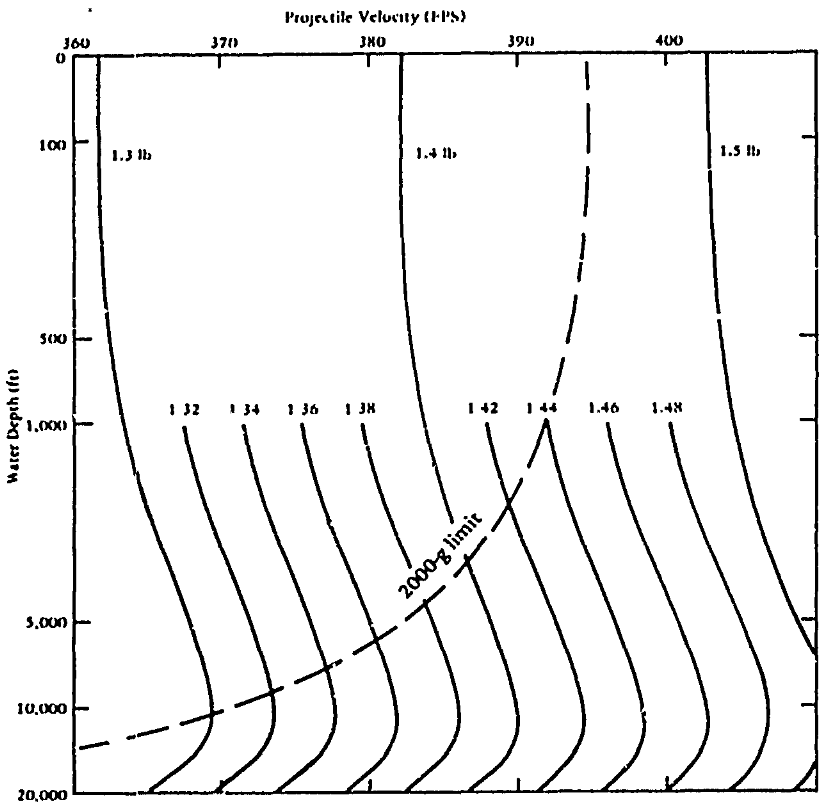

Figure 7. Projectile velocity versus water depth for the CEL 10K anchor at various charge weights. The projectile used is the 148-pound, 1 x 2-foot fluke; the propellant is M6, 0.0579-inch web.

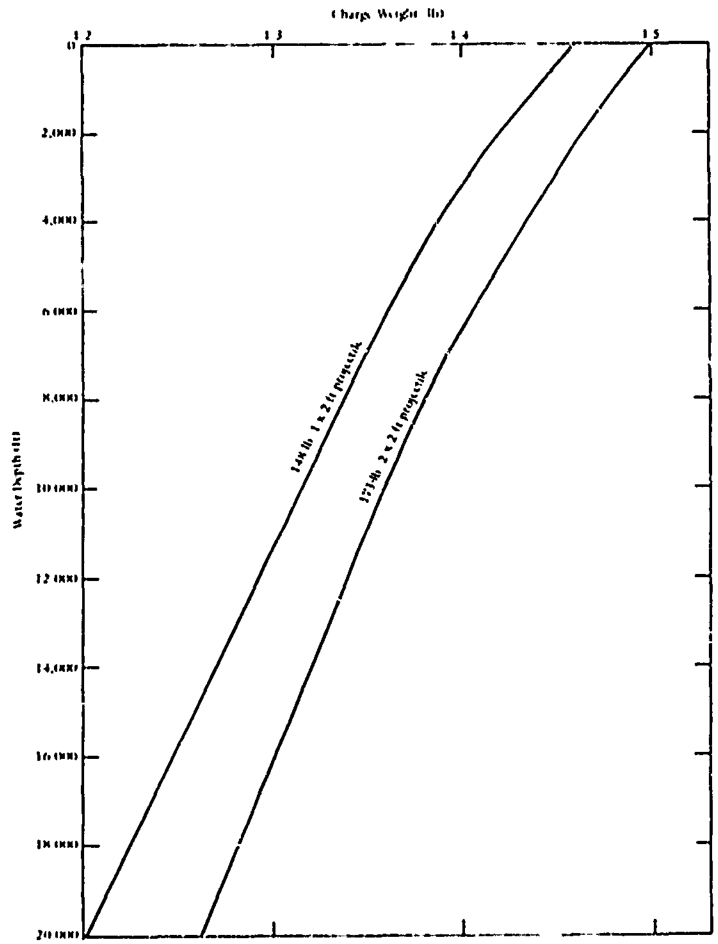

Figure 8. Charge weight versus water depth for the CEL 10K anchor using M6 propellant with 0.0579-inch web size.

TEST PROGRAM

Land Tests

The 10K anchor was tested to verify ballistic performance, watertight integrity, and structural soundness. The ballistics and structural strength were checked by conducting instrumented tests of the anchor on land at the Pacific Missile Test Center, Point Mugu, California. The hydrostatic seals were checked by a pressure test in CEL's Deep Ocean Laboratory facility.

The gun tube is a watertight container with seals designed to withstand water pressures of 20,000-foot (6,100 m) depths. However, the safe-and-arm device (S/A), which was purchased as a stock item from the Magnavox Company, was guaranteed to only 200 feet (60 m). The S/A and gun tube were assembled and tested to a simulated ocean depth of 600 feet (185 m) and 1,200 feet (365 m). The test procedure was to build up pressure to the maximum value, hold for 10 to 15 minutes, and then gradually release pressure. Two systems were tested to 300 psi (2 kPa), and, finding no leaks, the second two were tested to 600 psi (4 kPa). After testing, the anchors were disassembled and inspected for signs of leaks; each system was found to be watertight. Minor modification to strengthen the S/A body should allow the anchor to operate to 20,000-foot (6,100-m) depths.

The propellant system is designed to impart high velocity to the projectile in a short distance which results in high acceleration-induced stresses experienced by both projectile and gun assembly. By conducting test firings on land it was possible to examine both the ballistic performance of the gun system and the structural integrity of the launch vehicle. It was not feasible to use the actual anchor projectile during land tests, so an equivalent mass of steel was substituted.

The anchor was assembled and hung in a fluke-down vertical orientation from a wooden beam resting on a steel box frame. The anchor was then loaded, armed, and fired. Six tests were conducted with charge weights from 1.1 to 1.4 pounds (500 to 635 gm). Each test was instrumented for pressure measurements by a transducer and copper crush gages. High-speed movies were taken of the firing to determine projectile velocity and acceleration should the test results indicate performance problems with the propulsion system.

The last three tests included the use of a downhaul cable to determine the effectiveness of a new wire rope packing arrangement and the potential use of chain as a downhaul. The wire rope was used in the first test. The wire rope was faked into a sheet metal pack attached to the test support frame with the bitter end of the wire rope attached to the dummy anchor projectile. The chain downhaul was used on the last two tests. The downhaul chain was prepared by placing a length of 1/2-inch-diameter (13 mm) chain in tension and coating it with a two-part urethane epoxy. When the epoxy hardens, it holds the chain in a pretensioned configuration; thus, the chain can be used much like a cable, and the urethane coating is flexible enough to allow faking of the chain.

The land testing provided a severe test of the anchor's structural design. Upon firing, the launch vehicle would recoil upward through the wood support beam, rising as high as 200 feet (60 m) in the air before dropping to the ground. Although the accelerations during firing on land are similar to those attained underwater, the impact of the launch vehicle as it lands after its recoil is much more severe on land than in the water. No failures of major components occurred, and the minor damage that was sustained was entirely due to the launch vehicle impact, not to the actual firing accelerations. This problem is eliminated when the anchor is used underwater.

The ballistics performance indicated an under estimation of gun barrel pressures for each charge weight. Subsequent tests of the particular lot of propellant used indicated considerably different burn rate characteristics than are normally expected for M6 propellant. Rerunning the computer simulation with the new values accurately profiled the test pressures. Predicted and actual pressures are plotted in Figure 9. The pressure-time curves for the tests indicated a very smooth pressure buildup and release as is desirable. Examples of the pressure-time curve are given in Figure 10.

The new burn rate values do not seriously affect anchor performance above 10,000 feet (3,100 m) of water depth. However, below that depth, the propellant is completely burned before the piston leaves the gun barrel. No additional propulsion is available to drive the piston from the gun barrel; thus, as the depth increases, the ambient water pressure reduces the net propulsive force. The result is the decrease in projectile velocities below 10,000 feet (3,100 m) apparent in Figures 6 and 7. For anchoring below this depth a slower burning propellant must be used.

It was unnecessary to reduce the high-speed film to obtain velocity and acceleration data, because the agreement between predicted and actual results for the propellant system was good.

Sea Tests

The first sea tests of the 10K anchor were recently completed at the MILS cable installation at Midway Island. The anchors were to be used only for testing purposes, but a YTB scheduled to install heavier 20K anchors was withdrawn; therefore, the 10K anchor had to be used to provide a temporary four-point mooring for the ARS *Deliver*. The seafloor was coral, and very little was known about its strength characteristics. Only four sediment flukes were available; therefore, they were slightly modified on site to accept the downhaul cable directly into the fluke.

The anchors were installed from a 35-foot (10.7 m) workboat. The anchors were transported to the site slung from a small A-frame off the bow (Figures 11 and 12). A 6-ton (5.45 metric-ton) salvage winch was placed in the well deck, and it was used to control-lower the anchor to the seafloor. Each anchor was installed with 1.45 pounds (657 gm) of M6 propellant. A 1 x 2-foot (31 x 61-cm) fluke was used for the first

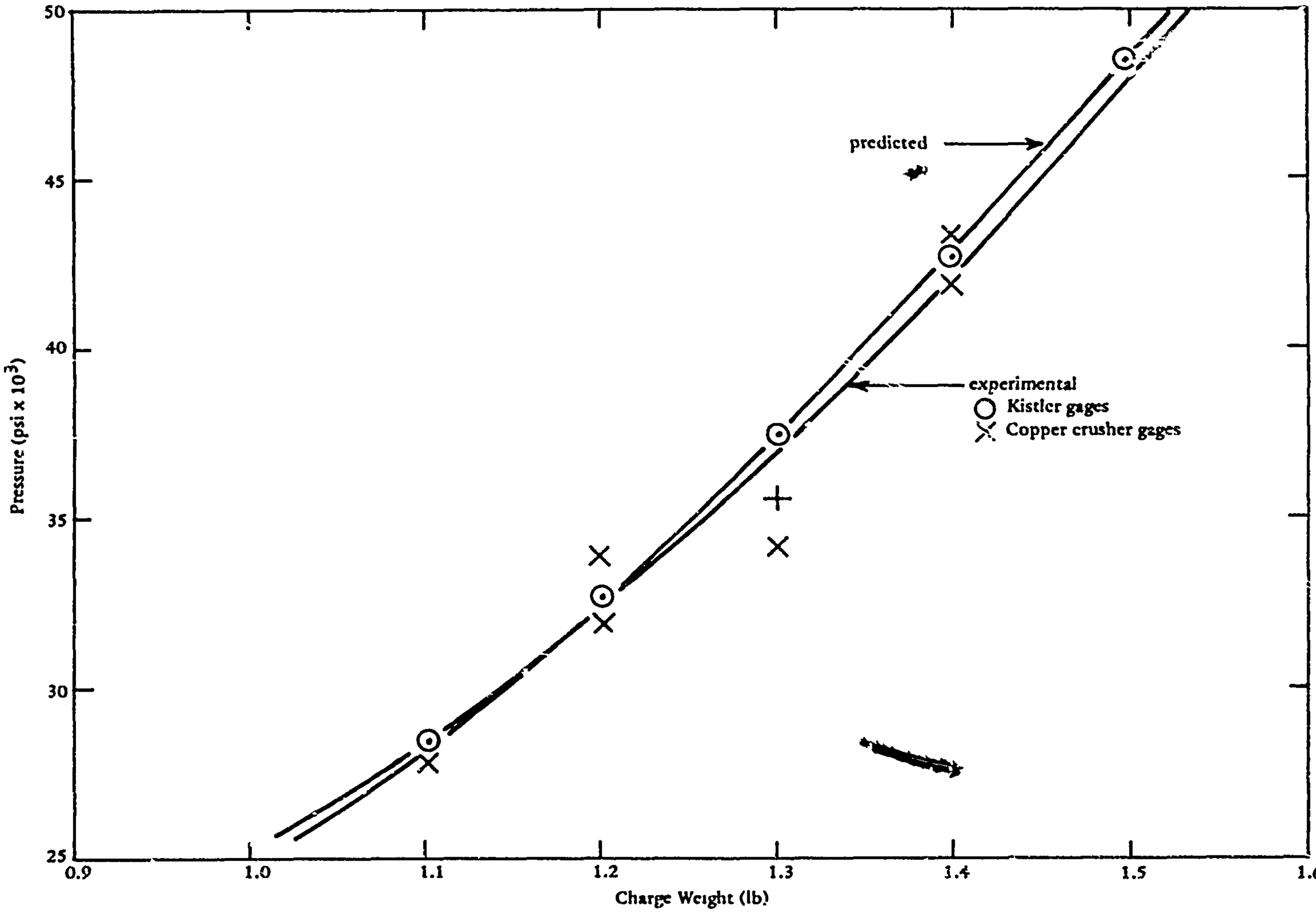

Figure 9. Plot of experimental and predicted pressures versus charge weight.

and third firings, while a 2 x 2-foot (61 x 61-cm) fluke was used for the second and fourth firings. The first two anchors were quickly installed in 59 feet (18 m) of water, penetrating 9 and 14 feet (2.8 and 4.3 m), respectively. This deep penetration indicated a rather soft coral or a layered media (coral/coral sand) at these two sites. The third anchor was installed in 112 feet (34 m) of water; this anchor was to be used as the starboard bow anchor. The fluke penetrated a short distance and was badly damaged. The initial assumption was that the fluke was unstable during penetration, and this caused the piston to separate from the fluke prematurely. However, a subsequent firing with a CEL 20K anchor at roughly the same location indicated that this coral was extremely hard. Since divers reported shallow penetration of the 10K anchor, the work boat proof-loaded the anchor to determine its status. The work boat easily pulled the anchor out. The front of the fluke was bent back, and the fluke could offer no holding capacity in the coral rubble produced during this penetration. The fourth 10K anchor was assembled and transported to the same site. This anchor was rapidly lowered to the seafloor and fired in almost a prone position. The rapid (almost free-fall) lowering caused the anchor to plane out. The fluke grazed the seafloor at a very shallow angle and landed on the surface a short distance away. The 10K with the 2 x 2-foot (61 x 61-cm) fluke will have to be lowered at a more reasonable rate, perhaps less than 400 fpm (120 mpm) to prevent kiting; this rate will be determined at a later date.

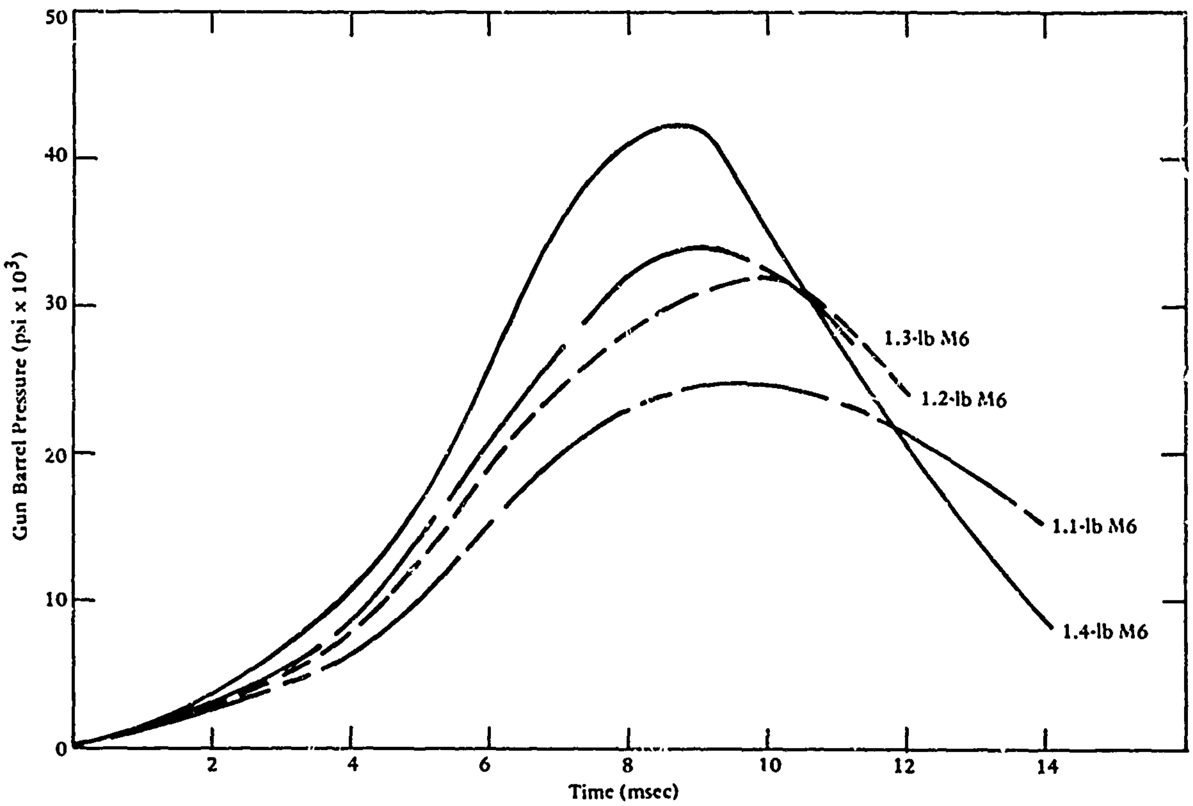

Figure 10. Pressure versus time for the land tests of the 10K anchor at four charge weights.

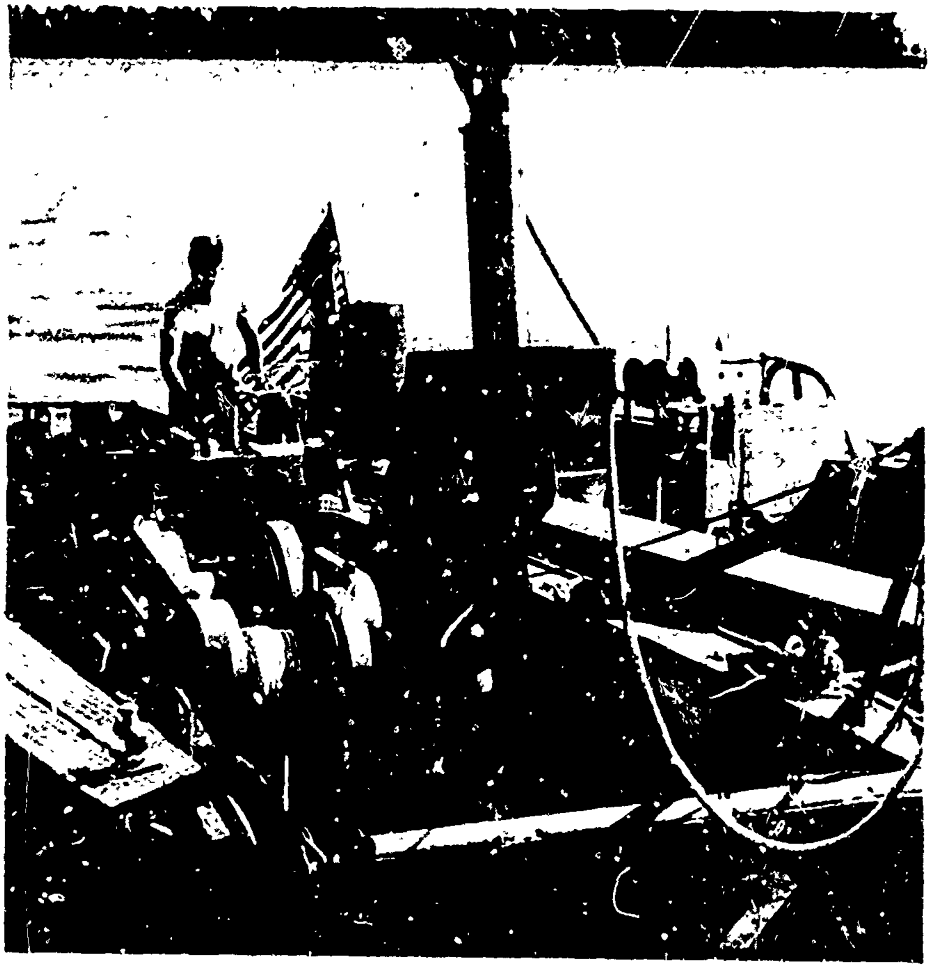

Figure 11. CEL 10K anchor being placed in a 35-foot workboat.

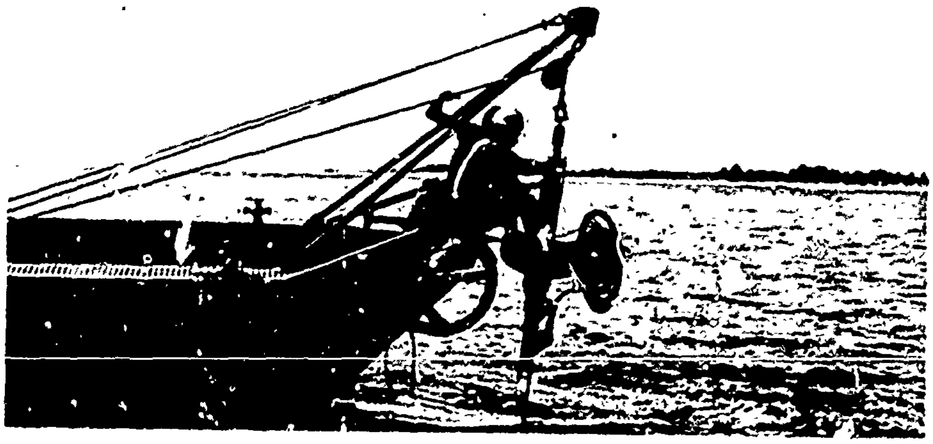

Figure 12. CEL 10K anchor being prepared for lowering from a 35-foot workboat.

The mooring was completed using two work boats lashed together to install two 20K anchors. Once the ARS was in its moor, the mooring lines were pretensioned. During use, one of the 10K anchors pulled out during a moderate storm, with 25-to-30-knot beam winds, 4-to-5-foot (1.2-to-1.5-m) seas, and strong beam currents, estimated to 2 knots. The peak static load sustained by the anchor was estimated to be about 30,000 pounds (135 kN); ship surge would increase this load. The other 10K anchor remained embedded throughout the operation and was left in place for further use or testing.

EVALUATION OF ANCHOR PERFORMANCE

The land tests verified the efficiency of the anchor's propulsion system and the structural design. The anchor is easily and quickly assembled due to its light component weight.

The firing system performed excellently; even at large angles of tilt, the anchor fired each time. The safe-and-arm device is simple and easily prepared for use and reuse.

The downhaul cable packing arrangement tested at Point Mugu and used at Midway proved to be ineffective. The wire rope tends to be kinked by the acceleration it experiences as the anchor is fired. The urethane-coated downhaul chain holds promise as a method of avoiding the abrasion problems that are present when anchoring in sand.

The soil flukes can be modified for use in coral; however, a separate projectile designed for this purpose, similar to the CEL 20K rock anchor,* would prove more effective, particularly in very hard coral bottoms. The large 2 x 2-foot (61 x 61-cm) fluke requires a slower lowering rate than the smaller 1 x 2-foot (31 x 61-cm) fluke to prevent tilting of the anchor system during descent and touchdown. Further investigation of the anchor's hydrodynamics is warranted if a free-fall mode is desired.

SUMMARY

The CEL 10K anchor is inexpensive to fabricate and simple to assemble and handle. Preliminary results indicate that the firing system functions reliably and that the gun system performance is predictable. The scant data available from ocean testing indicate that the anchor can satisfy its design capacity of at least 10 kips (45 kN) in coral; capacities in excess of 30 kips (135 kN) are possible if the anchor is satisfactorily embedded.

The Magnavox S/A functioned simply and reliably during both land and sea tests. The 10K anchor shows promise for providing the Navy with another propellant-actuated anchor with medium range (10 to 50 kips, 45 to 225 kN) holding capability. However, further testing or actual use will be required to provide the performance reliability data so necessary for a system of this type.

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* Taylor, 1976, Op. cit.

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